COMPARISON OF NUTRIENT CONCENTRATION IN FOUR FERTILITY TREATMENTS AFTER POULTRY LITTER APPLICATION TO ORCHARDGRASS AND SORGHUM-SUDANGRASS HAYFIELD SOILS

A Thesis

Presented to

The Faculty of the Department of Agriculture

Western Kentucky University

Bowling Green, Kentucky

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

by

Amanda Susan Canty

December 2002

COMPARISON OF FOUR FERTILITY TREATMENTS AFTER POULTRY LITTER APPLICATION TO ORCHARDGRASS AND SORGHUM-SUDANGRASS HAYFIELD SOILS

Date Recommended January 31, 2003

Becky A. Gilfillen
Director of Thesis

Bleugh

J McWilliam

Elmer Gray 1-31-03
Dean, Graduate Studies and Research Date

DEDICATION

I grew up with the notion that women can be anything or go anywhere and that college wasn't an option; the only choice to make was which school to attend. She's unique, one of the first women to graduate with an agriculture degree from Western and the inspiration for me to have chosen the same field. Women with degrees in agriculture in 1974 were not exactly plentiful and neither was the job market, so she did what she could, raised her babies, and when the youngest started kindergarten, off to school she went as well. She fought her way through raising four kids and finishing her nursing degree and when it was said and done, she took a job of mid nights so she could be with us throughout the day. Throughout childhood, adolescence, and my early stages of adulthood she has yet to relieve herself of any duties as a parent, caregiver, and now friend; she is my cheerleader when the game has long been over. This thesis is dedicated to my mother, Melody Edwards Canty, for instilling in me the determination to conquer the world, the sensibility to keep a clear head, and the passion for gardening. For everything that I am and have the potential to be, I thank you.

ACKNOWLEDGMENTS

Dad, Mom, Kate, Kevin, and Sarah Ruth—Thanks for inspiring me, encouraging me, and loving me. Because of the five of you, I know that whatever obstacle or crisis life may throw my way, I'll conquer and seize it. You are my greatest source of strength, and I love you all very much.

Raquel—I don't think there are words that do justice to what I need to say to you. You are my pal, my confidant, and the only person in the world who wears gasoline panties to take soil samples. Thank you for your encouragement and being a wonderful friend; wherever life may take us a piece of you and the memories of those times will always be a part of me.

Justin—Thanks for being my "bodyguard" when I needed one, I don't think I could have made all those late night trips alone. You helped me in more ways than you will ever know, and your patience with me is far beyond that of anyone else I have ever known, for that I have the deepest gratitude.

Dr. G—Thank you for your patience and constant reassurance that there was a light somewhere at the end of the tunnel. I could not have made this journey successfully without your help.

Dr. Willian—It's your world, I'm just living in it.

Byron B. Sleugh—What's going on?!?! Thank you for your friendship and endless advice. We could not have been luckier when you were added to the faculty. You are a wonderful person, and I will never forget your kindness. May God bless you, Andrea, and those three little heathens!!

To the Faculty and Staff of the WKU Ag. Department—I will treasure each memory I have of WKU and my time as an "aggie." Some of the greatest friendships and experiences life has been so gracious to bestow upon me were created in the ag. department, for that I am eternally grateful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURES (cont.) PAGE

Comparison of Nutrient Concentration in Four Fertility Treatments After Poultry Litter Application to Orchardgrass and Sorghum-Sudangrass Hayfield Soils

Amanda Canty December 2002

Directed by: Dr. R.A. Gilfillen, Dr. B.B. Sleugh, and Dr. W.T. Willian

Department of Agriculture Western Kentucky University

Field experiments were established in 2001 at the Agricultural Research and Education Complex in Bowling Green, Kentucky to evaluate soil fertility values before and after poultry litter application to orchardgrass and sorghum-sudangrass hayfields. A randomized complete block design was utilized with each treatment being replicated four times. Orchardgrass plots consisted of sixteen 7.6 m rows, 91 m in length and separated by alleys 4.6 m in width. Sorghum-sudangrass plots consisted of sixteen 7.6 m rows, 60.96 m in length and separated by alleys 4.6 m in width.

Four separate fertility treatments were utilized: inorganic fertilizer (I), poultry litter applied to meet nitrogen requirements (N), poultry litter applied to meet phosphorous requirements (P), and poultry litter applied to meet phosphorous requirements with a supplemental inorganic fertilizer (NP). In the poultry litter applications, plant available P was estimated to be 80% while N availability was estimated at 50% the first year. Fifteen soil samples were taken in a random, representative manner from each plot of orchardgrass and sorghum-sudangrass prior to litter application and after each harvest. Soil samples were analyzed for pH, N, P, K, Mg, Ca, Fe, Cu, and Zn levels, which were evaluated based upon fertilizer treatment differences.

Water pH has statistically remained the same thus far, indicating that it is currently not determining nutrient availability among treatments in orchardgrass and sorghum-sudangrass soils. Nitrate concentrations exhibited increases in treatments N and P for orchardgrass soils, while sorghum-sudangrass soils indicated all three treatments N, I, and P were different from each other. There were no differences among treatments for ammonium in orchardgrass soils; however, sorghum-sudangrass soils exhibited a higher concentration in treatments P and I. In both orchardgrass and sorghum-sudangrass soils, treatment N exhibited an increase in phosphate, copper, and zinc concentrations over all other treatments; magnesium and potassium concentrations were highest in treatment N in sorghum-sudangrass hayfield soils. Potassium concentrations were higher in treatments P and N in sorghum-sudangrass soils and the NP and I in orchardgrass soils. Sorghum-sudangrass soils indicated a higher K concentration in treatment N from all other treatments. While orchardgrass soils exhibited no differences in Mg, sorghum-sudangrass soils indicated a higher amount in treatment N from all other treatments. Copper and zinc both exhibit a higher concentration in treatment N in comparison to all other treatments in both orchard and sorghum-sudangrass soils.

CHAPTER I

INTRODUCTION

The poultry industry is currently a major source of agricultural income in Kentucky as well as for many other southern states. At a time when the agricultural economy is suffering from low commodity prices, the poultry industry has become an alternative to some traditional agricultural crops. Poultry production in Kentucky has increased dramatically since 1990, and poultry numbers have risen to approximately 500 operating farms since that time. In 1998 the poultry industry accounted for 640 million dollars in income with those numbers increasing for 1999 and 2000, but expected to level off in 2001 (Skillman, 2000). Poultry has been a bright spot as the overall agricultural economy suffers financially, not having been affected by drought or markets.

Broiler production for Kentucky in 2001 totaled 1.29 billion pounds from 253.4 million birds. Value of production was $504 million, making broilers the second largest source of cash receipts for Kentucky Farmers. Compared with 1999, broiler production has increased by 6%. Kentucky ranks 20 out of 45 in the U.S. in all chickens and 12 out of 23 in the U.S. in broiler production (www.nass.usda.gov/ky, November 25, 2002). Broilers, however, produce as much as two pounds of litter per bird or about one ton per year per 1,000 birds: about 81 cubic feet of litter for each 1,000 birds (Poultry Water Quality Handbook, 1998). In 1996, nearly 15.2 billion pounds of litter were produced by broiler operations in the U.S.—enough to cover 1,619 miles of two-lane highway to a depth of three feet. The "litter highway" can be imagined as the distance from New

Orleans, Louisiana, to Chicago, Illinois, and on to Fargo, North Dakota (National Agricultural Statistics Service, 1997).

That much litter can and must be responsibly handled. Poultry litter is often applied to pastures and crops as an organic fertilizer. Practice of spreading poultry litter can be beneficial when soil and manure nutrient testing are integrated with crop nutrient needs to determine amount and timing of application (Poultry Water Quality Handbook, 1998). This integration makes it possible to approach land application as a wise use of resources rather than as a disposal method. The objective of these studies were to determine nutrient concentrations in orchardgrass and sorghum-sudangrass hayfield soils after poultry litter application.

CHAPTER II

LITERATURE REVIEW

The increased quantity of poultry in Kentucky has been accompanied by increased production of manure and litter. These by-products must be safely handled to ensure that they do not lead to air, soil, or water pollution. Traditional use for these by-products is land application, but there are other methods for utilization of poultry waste that include composting for gardens and lawn uses, and as a feed for cattle and other ruminants. Poultry waste, as well as wastes from other sources, has the potential to pollute the environment when improperly handled or when abused in land application.

Poultry litter is often used synonymously with the words poultry manure; however they are two different entities. Poultry manure is a mixture of defecation and urine while poultry litter is comprised of these plus water, feathers, and bedding materials such as wood shavings and sawdust. Rice and/or peanut hulls may also be part of the composition depending on bedding availability.

Nutrients Found in Poultry Manure/Litter

Poultry raised for commercial purposes produce large amounts of manure that is a collectible resource, unlike manure of free range or pastured animals. Manure contains valuable plant nutrients and other chemicals that, if properly managed, can be returned to land or processed for other uses (Poultry Water Quality Handbook, 1998). All crops can use poultry litter as a source of fertilizer. However, because one of the primary fertility values of poultry litter is nitrogen (N), legume crops would not potentially benefit as much. Pastures with legume-grass mixtures will not respond as well to poultry litter as pure grass pastures. Non-legume crops that have responded well to poultry litter include corn, sorghum, millet, small grains, cotton, grass pastures, and hayfields (Alabama Extension Service, 1992). Compared to inorganic fertilizers, organic amendments offer several advantages (Table 1).

High nitrate levels in groundwater and high phosphorous (P) levels in surface water may be a concern in that too much litter or fertilizer is being applied on too small an area. Yet the fact that poultry litter is high in nutrients is precisely its value. Nutrients in this source make it an excellent soil fertilizer and conditioner. Growers can maximize benefits of having this resource and help protect local water resources from high nutrient levels by planning and operating an effective nutrient management system (Poultry Water Quality Handbook, 1998).

Poultry waste disposal has become a major problem in recent years due to large-scale, concentrated operations. When poultry houses are cleaned during spring, litter is normally applied to nearby crops such as fescue or bermudagrass pastures. Since the poultry industry is concentrated geographically, excess litter is often applied. As a result, excess nutrients in litter that are not taken up by the crops can contaminate surface and groundwater through runoff and leaching (Buchberger et al., 1993). Sims & Wolf (1994) and Jongbloed & Lenis (1998) found that nutrient buildup under excessive fertilization with swine effluent or poultry litter can also be a major problem. Excess nutrients can adversely impact water quality through runoff and leaching and also by creating nutrient imbalances and possible toxic levels in plant tissues (Kingery et al.,

Table 1. Advantages and Disadvantages of Organic and Inorganic Amendments as Fertilizers.

Material	Advantages	Disadvantages
Inorganic Fertilizers	•Convenient •Transport and handling costs lower. •Quick crop response.	•Some easily leached. •Nutrient availability is tied to time of application and is not sustained.
Organic Fertilizers	•Improves soil structure. •Controls erosion. •Supplies wide range of nutrients. •Improves water-holding capacity.	•Dilute nutrient source. •High transport cost. •May be difficult to evenly apply. •High C/N ratios may rob N from soil.

(The Ohio State University Bulletin 804, 1990)

1994). Pastures and hayfields have been commonly used as sites for animal waste application. Few nutrients are removed from the farm by cattle grazing (Ball et al., 1991), but hay production and sales can remove excess nutrients from the land.

Broiler litter generally contains about 3-4% N, 2-3% P_2O_5, and 2% K_2O on a wet-weight basis. Average nutrient content in pounds per ton is listed in Table 2. However, the concentration of nutrients in litter varies greatly from one poultry operation to another, so litter should be tested to determine its nutrient content before application (Alabama Extension Service, 1992). Factors affecting nutrient content of poultry litter include bird type, feed composition and efficiency, and building management factors. Building management includes cleanout frequency, type of waterer and management, decaking management, and use of litter additives such as alum. Unpredictability of nutrient content from house to house makes nutrient testing of manure an essential part of using poultry litter as a fertilizer for crop production (University of Missouri Extension Service, 1999). Soil tests should always be conducted first to ensure that litter or other forms of fertilizer would be a wise choice for the crop.

Forage species influences levels of nutrient concentration and retention. The amount of nutrients needed also increases as the plant ages. The older the plant, the greater the amount of nutrients it contains, until it peaks at full maturity. Age-induced increase in nutrient content is due to an increase in total dry matter. However, a frequent cutting of immature plants maximizes nutrient removal because fast-growing plants remove more nutrients than slower growing, mature plants do. These findings suggest that managing forage plants for growth and maturity and then harvesting them as hay for

Table 2. Various Nutrient Contents in Pounds per Wet Ton of Poultry Litter

Nutrient	Pounds per Ton (wet wt.)
Total N	69
Ammonia N (NH_4-N)	16
Nitrate N	0.1
Phosphate (P_2O_5)	82
Potash (K_2O)	38
Calcium (Ca)	38
Magnesium (Mg)	16
Manganese (Mn)	0.4
Sodium (Na)	15
Zinc (Zn)	0.2
Sulfur (S)	14
Iron (Fe)	2
Copper (Cu)	0.1
Note: Data are based on poultry litter from nine Missouri broiler houses after three to six flocks. All values are on a pounds per ton basis. (wet wt.)	

(Missouri Extension Publication G9340 May 1, 1999) selling off-farm would maximize nutrient removal and lessen the environmental impact of excess nutrients (Pederson, 2002).

Nitrogen

Nitrogen is the most frequently deficient macronutrient in crop production; therefore, most non-legume cropping systems require large N inputs (Tisdale et.al, 1985). The ultimate source of N used by plants is N_2 gas, which constitutes 78% of the earth's atmosphere. Higher plants cannot metabolize N_2 directly into protein; therefore N_2 must be converted to plant available N by microorganisms, atmospheric electrical discharges forming nitrogen oxides, or manufacture of synthetic N fertilizers. Quantity of N in manure and availability to plants varies greatly and depends on the nutrient content of the animal feed, method of manure handling and storage, quantity of added materials (i.e., bedding, water, etc.), method and time of application, soil properties, and intended crop. Most animal waste contains 75 to 90% water. Storage and handling usually reduce water content in solid storage systems. With total N contents ranging from between <1 and 6%, estimated organic N is 50 to 75% of total N, while the remaining 25 to 50% of total N is inorganic (Table 3). Thus, manure N availability to plants predominantly depends on mineralization of organic N in manure. Organic N fraction in manure is composed of both stable and unstable components. Urea and uric acid are the main components of unstable organic N and are readily mineralized to plant available NH_4^+. Since NH_4^+ can be converted to NH_3 gas under alkaline soil conditions, significant volatilization losses of manure N are possible, ranging from 15 to 40% of total N (Havlin et al., 1999). Most of the NO_3^--N, and approximately one-third to one-half of organic N, is available the first year after application. Inorganic N fertilizer is used for application; not all of N will be

Table 3. Contribution of Various Nitrogen Inputs for Crop Production and the Total Percentage Used of Each

N Source	*Total Amount (million tons)*	*Percentage of Total*
Commercial N	8.55	57
Legumes, crop residues	3.74	25
Animal manures	2.14	14
Other sources	0.52	4

(USDA, 1992)

available for crop uptake. Some N may be lost to leaching and denitrification or incorporated into soil organic matter, and remain fixed in soil. Amount of N available the second year after litter application is difficult to predict because availability is highly dependent on climatic conditions and crop grown (The Ohio State University Extension Service, 1990).

Of the three major nutrients in poultry waste, N is most complex and hence potentially likely to contribute to environmental problems (Poultry Water Quality Handbook, 1998). Translocation of manure constituents represents not only a loss of beneficial nutrients but also a threat to the quality of downstream creeks, rivers, and lakes, since organic matter poses a threat of depressed dissolved oxygen and nutrients may promote eutrophication. Concerns regarding potential environmental impacts of land-applied animal manures are increasingly common in regions of concentrated production (Edwards & Daniel, 1993).

Most poultry litter in northwest Arkansas, the region with the greatest poultry concentrations, is applied as a fertilizer to nearby pasturelands consisting of bermudagrass and tall fescue (Govindasamy et al., 1994; Buchberger et al., 1993). In field corn (*Zea mays L.)* plots, poultry manure in excess of crop needs resulted in considerable downward movement of NO_3^- through soils as well as increased NO_3^- in the groundwater aquifer (Kingery et al., 1994). Heavy land application of poultry manure was associated with elevated NO_3 levels found in well water (Kingery et al., 1994). In northwest Arkansas, the number of wells with NO_3 -N levels above the maximum contamination level (MCL) of 10 ppm has increased in the past few years (Steele et al., 1990). In this same period, the poultry industry experienced substantial growth. A summary of Arkansas water mineral quality data, in 1971 and 1972, reported less than 2.2% of sample wells tested were above the MCL for nitrates; whereas, in 1986, 14% of tested wells were above the MCL (Madison & Brunett, 1985). The Arkansas non-point pollution assessment concluded from 1988 data that in the Ozark Highlands region, "nitrate levels....are consistently high" (Arkansas Dept. of Pollution Control and Ecology, 1990). Excessive levels of nitrates in drinking water can cause methemoglobinemia ("blue-baby" disease) in infants and is suspected to cause an increased incidence of cancer in the general population (Buchberger, 1991). Laboratory animals exposed to excess nitrates have proven susceptible to heart diseases and behavioral problems. Therefore, there is an urgent need to determine safe disposal and optimal use of poultry litter as a soil amendment on farmlands (Buchberger et al., 1993).

Kingery et al. (1993) found that long-term litter applications, as compared to no litter, resulted in an accumulation of soil organic matter and total N. An accumulation of total N owing to litter applications is consistent with Huneycutt et al. (1988), who applied 6 tons litter acre^{-1}, which contained approximately 480 pounds of total N. Litter was applied to tall fescue, which produced yields equivalent to commercial fertilizer rates of 200 to 300 pounds of N acre^{-1}. By assuming that approximately 60% of total N in litter became available through mineralization, they estimated that about 228 pounds N acre^{-1} was supplied to tall fescue, annually. Their results suggested that there was a significant pool of residual N associated with litter application.

Phosphorous

Phosphorous is most plant available near a pH of 6.5 for mineral soils and about a pH of 5.5 for organic soils. Soil pH, because of its influence on the presence and solubility of calcium, iron, and aluminum, and also its effect on bacterial growth, greatly influences available P. There is no efficient mechanism in the soil to retain $H_2PO_4^-$ or HPO_4^{2-} ions in large quantity as exchangeable anions. Thus, much of P used by plants, other than that from applied phosphate fertilizers, is believed to come from organic phosphates released by decomposition of matter (Miller & Donahue, 1995). Soil P can be classified generally as organic or inorganic, depending on the nature of the compounds in which it occurs. Levels of organic P in soils vary enormously, ranging up to 0.2% by weight. Inorganic fraction of soil P is much less at .05% by weight (Miller & Donahue, 1995) and occurs in numerous combinations with iron, aluminum, calcium, fluorine, and other elements. Solubility of these compounds in water varies from sparingly soluble to insoluble. Organic P content of mineral soils is usually higher in the surface horizon than it is in subsoil because of the accumulation of organic matter in the upper part of the soil profile. Phosphorous is absorbed by plants largely as the primary and secondary orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}), which are present in soil solution. The amount of each form depends largely on soil solution pH. At a near neutral pH (7.22), there are approximately equal parts of $H_2PO_4^-$ and HPO_4^{2-}. Below this pH, $H_2PO_4^-$ is the main form and it is predominant in many agricultural soils. Plant uptake of HPO_4^{2-} is much slower than with $H_2PO_4^-$. Concentration of phosphate ions in soil solution is influenced by rate and extent to which this element is immobilized by biological factors and by reactions with the mineral fraction of soils. Soils high in soluble iron and aluminum react with ortho and polyphosphates to form a variety of insoluble compounds, including variscite and stregtite, which are largely unavailable to plants. Soluble phosphates also undergo reactions in soils high in clays (especially those of the 1:1 type and accompanying hydrated oxides of iron and aluminum) which convert them to forms only slightly available to plants (Tisdale et al., 1985).

When the amount of P added to soil as fertilizers exceeds removal by crop uptake, P residues gradually increase with a corresponding rise in P concentration in soil solution. This rise in P concentration leads to a rapid decline in effectiveness of soluble P fertilizers over the first few months to years after application. Potential contributions of residual P to succeeding crops are frequently considered insoluble and ultimately unavailable forms that tend to decline with time. There can be lasting benefits from residual P; its duration and magnitude depend largely on rate of initial applications, crop removal, and buffering capacity of soil for P. Performance of initial applications of P cannot be fully assessed from just one or two consecutive crops. On both acidic and alkaline soils, substantial benefits from residual P can persist for up to 10 years. Duration of response will be influenced by amount of residual P available in that soil (Tisdale et al., 1985). Applying poultry waste to land at rates based on supplying N needs of grain or cereal crops can lead to a P buildup in soil. Planting forage crops in rotation with grain crops will help remove excess P. Maintaining soil pH at the recommended level is also an effective and economical practice for maximizing P efficiency. Crops use P most efficiently when the soil pH is between 6.0 and 7.0. Soil phosphate levels are an important consideration in calculating litter application rates. Land applications should be made only to soils that do not already contain excessive phosphate levels (Poultry Water Quality Handbook, 1998).

If litter is applied to a dormant perennial or dead annual tropical grass hayfield or pasture during winter and spring, the presence of actively growing temperate forage will reduce potential for P loss, largely by reducing sediment movement in runoff (Sharpley et al., 1994).

Non-point source pollution created by agriculture is one major issue of intensive crop and livestock production. Recent studies indicate that eutrophication from agricultural non-point source pollution, especially from P, is of growing concern (Govindasamy et al., 1994). Because of large amounts of accumulated soil P associated with litter applications, P-loading criteria should be a fundamental component of litter application guidelines (Kingery et al., 1993).

Potassium

Soil K is generally believed to exist in four categories based on its availability to crops. These groups increasing in order of availability along with estimates of approximate amounts in each are as follows: mineral (structural) 5000 to 25,000 ppm; nonexchangeable (fixed or scarcely available) 50 to 750 ppm; exchangeable 40 to 600 ppm; and solution, 1 to 10 ppm.

Potassium is absorbed by plants in larger amounts than any other mineral element except N. Although total K content of soil is usually many times greater than the amount taken up by a crop during a growing season, in most cases only a small fraction of it is available. Phosphorous concentration of the earth's crust is only 0.11%, whereas that of K averages about 1.9%. Concentration of K in soil normally varies between 0.5 to 2.5% and averages about 1.2% (Tisdale et al., 1985). In soils, K is released from weathering minerals and from cation exchange sites. Primary minerals containing K have very low solubility; therefore K available to plants during a growing season is supplied from the soil's exchangeable K reservoir (Miller & Donahue, 1995). Plants take up potassium as the K^+ ion mainly from, or via, soil solution. Concentration of K needed in soil solution will vary considerably depending on type of crop and the amount of growth desired. (Tisdale et al., 1985). In neutral and basic soils soluble K^+ alone may be adequate to supply modest plant needs. In moist soils, particularly acidic ones, exchangeable K^+ is the major source of K to plants (Miller and Donahue, 1995).

Potassium in poultry waste is a soluble nutrient similar to fertilizer K. It is immediately available to plants when it is applied. Potassium is fairly mobile but does remain in soil to help supply plant needs; such as formation of strong stems, resistance to disease, and formation and transfer of starches, sugars, and oils. Excessive amounts of K can inhibit or restrict growth of some plants at certain stages of development. Small amounts of K may be leached to groundwater, especially in sandy soils; however, K is usually not considered a threat to water quality or considered a pollutant (Poultry Water Quality Handbook, 1998).

Benefits of Application

Poultry litter has a long history of use as a source of plant nutrients and an amendment for agricultural land. Land application of manures fulfills the dual roles of preventing unacceptable manure accumulation and fertilizing receiving fields (Edwards & Daniel, 1993). When properly handled, poultry litter is the most valuable of all manures produced by livestock because of its ability to be a collectible resource that is high in N as well as other valuable nutrients. It can be an excellent fertilizer material for growing crops because it reduces potential water pollution, need for commercial fertilizer, and improves soil productivity (Poultry Water Quality Handbook, 1998). These findings are similar to those of Kingery et al. (1993) stating that manure and other by-products enhance productivity and soil quality of grazing lands by increasing soil organic matter content, improving soil moisture holding capacity, and supplying valuable nutrients. Also stated was that poultry litter applications can provide benefits to pasture productivity such as higher soil pH and a more adequate supply of plant and animal nutrients.

Concerns of Application

Kingery et al., (1994) found that field trials with cattle on tall fescue pastures fertilized with broiler litter strongly indicated fescue toxicity problems due to high levels of N in plant tissue. Also, high application rates of poultry manure in field plots have reduced germination and adversely impacted growth and yield of corn due to excessive soil salinity. Concentrations of extractable P, K, Ca, and Mg indicate an accumulation of these elements in littered soils as compared with non-littered soils. Soil concentrations of extractable Cu and Zn for long-term littered pastures were also higher in littered than in non-littered pastures. Additionally, repeated litter applications at high rates may cause potentially toxic levels of Cu and Zn in soil (Kingery et al., 1993).

Environmental Implications

The overriding environmental issue facing producers is to prevent poultry waste from adversely affecting water quality. Potential water pollutants from on-farm poultry operations can be classified as (1) nutrients and salts, (2) organic materials, (3) bacteria, and (4) viruses (Poultry Water Quality Handbook, 1998).

Translocation of manure constituents represents not only a loss of beneficial nutrients but also a threat to quality of downstream creeks, rivers, and lakes since organic matter poses a threat of depressed dissolved oxygen and nutrients may promote eutrophication. Concerns regarding potential environmental impacts of land-applied manures are increasingly common in regions of concentrated production (Edwards & Daniel, 1993).

The amount of manure applied and biochemical conversion processes such as ammonia volatilization and plant uptake affect the quantity of manure constituents present in the soil-plant matrix at time of a rainfall event and therefore influence potential magnitude of constituent losses. However, if wind erosion and subsurface contributions to surface flows are neglected, then application of manures such as poultry litter can degrade surface water quality only in connection with runoff-producing rainfall or irrigation. Runoff can transport manure constituents in soluble form (e.g., NO_3), sorbed to eroded soil (e.g., NH_4 and P), and as suspended matter. Both volume and rate of runoff are critical factors related to the offsite movement of manure constituents (Edwards & Daniel, 1993). Though it remains to be determined, it is likely that current application practices can result in NO_3 -N concentration in excess of recommended 10 mg L^{-1} limit (U.S. EPA, 1976).

No explicit state environmental policy on P handling exists yet; however, recommendations have been suggested that any producer farming land that has elevated levels of P not apply poultry litter to improve crop production (Arkansas Cooperative

Extension Service, 1992). More specifically, recommendations suggest that no poultry litter should be applied if soil test P concentrations exceed 300 pounds per acre, irrespective of marginal costs and benefits associated with one more unit of poultry litter application on that piece of land. State Best Management Practices (BMP) are defined to include adherence to state Extension recommendations. Ideally, environmental policies should consider a variety of soil characteristics such as productivity, erosion potential, salinity, porosity, and assimilative capacity as well as other characteristics such as proximity to surface and groundwater and slope of the land (Govindasamy et al., 1994).

Tufft and Nockels (1991) indicated that As, Co, Cu, Fe, Mn, Se, and Zn are added to poultry diets to prevent diseases, improve weight gains and feed conversion, and increase egg production. Most of the metals pass directly through the bird, which leads to elevated levels in manure. Several researchers have shown that metal concentrations in poultry diets are highly correlated to that in manure (Morrison, 1969; Kunkle et al., 1981). Kunkle et al. (1981) found Cu concentrations in poultry litter were linearly related to that in feed; however, values found in manure were concentrated by up to a factor of 3.25 times compared to values in feed. Stephenson et al. (1990) found that Cu levels in manure were quite variable, with a range of 25 to 1003 mg Cu kg^{-1} litter. Several workers have shown that soils receiving applications of poultry litter for many years have high concentrations of As, Cu, and Zn, particularly near the soil surface (van der Watt et al., 1994; Kingery et al., 1994). These studies indicate a potential for non-point source metal pollution from fields fertilized with poultry litter. Edwards et al. (1997) conducted a study on small plots to determine effectiveness of vegetated filter strips in reducing metal runoff from land fertilized with broiler litter. They found Cu and Zn concentrations in runoff water as high as 0.7 and 0.1 mg L^{-1}, indicating a potential problem.

The objective of these studies were to determine nutrient concentration in orchardgrass and sorghum-sudangrass hayfield soils after poultry litter application.

CHAPTER III

MATERIALS AND METHODS

Two field experiments were established during 2001 at the Agricultural Research and Education Complex of Western Kentucky University, Bowling Green, Kentucky. Evaluation of soil fertility levels after poultry litter application to orchardgrass and sorghum-sudangrass were observed. Research was conducted on a Pembroke silt loam (Mollic Paleudalf) having a slope of 0-2%. A randomized complete block design was utilized with treatments replicated four times. The orchardgrass stand was approximately seven years of age, and sorghum-sudangrass was sown in early spring.

Orchardgrass

The orchardgrass area measured one acre in size and contained sixteen individual plots measuring 7.6 m x 91.4 m and separated by alleys 4.6 m in width. Fertility treatments were poultry litter applied according to nitrogen recommendations (N); poultry litter applied according to phosphorous recommendations (P); an inorganic fertilizer based on recommendations (I); and poultry litter applied according to phosphorous recommendations with a supplemental inorganic nitrogen fertilizer (NP). Fertility recommendations based on soil test results are shown in table 4. All litter and inorganic fertilizer applications were based on soil test results. All litter application was based on 50% N and 80% P availability the first year.

Table 4. Soil Fertility Recommendations (kg ha^{-1}) of Orchardgrass and Sorghum-Sudangrass Hayfield Soils in 2001

	Lime	N	P_2O_5	K_2O	S	Zn
Orchardgrass	0	193	74	91	12.5	2
Sorghum-Sudangrass	0	269	67	118	8	8

Sorghum-Sudangrass

Sorghum-sudangrass was seeded on two-thirds of an acre on May 17, 2001. Plots were fertilized one day prior to planting with the same fertility regime as the orchardgrass (Table 4). Plots were 7.6 m x 61 m and separated by alleys 4.6 m in length.

Litter Application

Litter application was split between two applications for orchardgrass and one for sorghum-sudangrass plots. Initial orchardgrass application was spread over March 22, 26, and 30, 2001 and second application on August 30, 2001. Sorghum-sudangrass fertilization was completed May 16, 2001. Litter analysis for all nutrients on a dry weight basis are listed on Table 5.

First litter application in Table 6 refers to the first application to orchardgrass (split). Second application was the remaining split application to orchardgrass. Table 7 refers to litter application rates to sorghum-sudangrass hybrid. To determine the amount of litter needed for N, P, and NP plots, seven individual five-gallon buckets were loaded with litter material and an average mass was taken. After filling the buckets, litter was transferred into a tractor bucket loader, and then to a manure spreader. For all litter-applied plots, a manure spreader was calibrated to expel the correct amounts within the plot area. For inorganic fertilizer application, a traditional cone-style fertilizer spreader was utilized.

Table 5. Kilograms of Nutrients per Megagram of Litter Application

First Application	Second Application
22.15 Kg N	30.44 Kg N
42.46 Kg P	42.01 Kg P
31.64 Kg K	35.08 Kg K
32.8% moisture	23.9% moisture

Table 6. Fertilizer Application Rates to Orchardgrass Hayfield Soils in 2001.

Fertilizer	March				August			
	N	I	NP	P	N	I	NP	P
Poultry Litter (Mg/ha)	12.7	0	1.6	1.6	8.23	0	1.42	1.42
34-0-0	0	246	230	0	0	246	230	0
5-20-20	0	219	0	0	0	219	0	0

Table 7. Fertilizer Application Rates to Sorghum-Sudangrass Hayfield Soils in 2001.

Fertilizer	May			
	N	I	NP	P
Poultry litter (Mg/ha)	9.93	0	1.23	1.23
34-0-0	0	528	463	0
5-20-20	0	225	0	0
0-0-60	0	56	0	0

Soil Sampling

Soil samples were taken prior to fertilizer application for both orchardgrass and sorghum-sudangrass fields, as well as, prior to each harvest. Approximately fifteen samples were taken within each plot to a depth of 10cm for orchardgrass and a depth of 15cm for sorghum-sudangrass plots. These depths differ due to a previous establishment of orchardgrass that required no mechanical disturbance of soil and conventionally tilled seedbed prepared for sorghum-sudangrass. Initial soil samples were taken on March 20, 2001 and May 16, 2000 for orchardgrass and sorghum-sudangrass plots, respectively. Consecutive samples were taken May 4, June 26, August 11, and September 10, 2001 prior to harvest of the orchardgrass. Consecutive samples for sorghum-sudangrass were taken July 5, August 15, and October 3 prior to harvest.

Soil Testing Methods

All soil samples were air-dried, ground, and sieved prior to analysis. Soil samples were analyzed for water pH with the 1:1 (10mL distilled water: 10g soil) extraction and measured by a glass electrode pH meter. Buffer pH was determined using SMP Buffer (pH 7.5) in the above mixture with 20 mL of SMP buffer. Mehlich-3 test (M3) was developed for routine analyses of P, K, Ca, Mg, sodium (Na), Cu, Zn, Fe, and micronutrients. Finally, the micronutrients (Cu, Zn, Mn, and Fe) were extracted by NH_4 and the chelating agent EDTA (Carter, 1993). Soluble materials were extracted using M3 and then analyzed with Inductive Coupled Plasma (ICP). The ICP has unique physical properties that make it an excellent source for vaporization, atomization, ionization, and excitation of elements. Total P analysis of soils requires the conversion of insoluble materials to soluble forms suitable for colorimetric procedures. Interpretations for P must be used with one very important consideration. They apply only when a colorimetric method is used to measure P solubilized by the extractant. A soil test is composed of two parts: the extraction of available P from the soil, which defines the soil test method, and the determination of P solubilized by the extractant. The colorimetric method most widely used in soil testing is similar for all P tests, and measures a blue color that develops with different intensity depending on the P concentration in the extracted solution (Page et al., 1982).

A soil extraction using 2M KCl and analyzed on an instrument called a Lachat determines NH_4 and NO_3^- analysis. It is a flow injection analysis that determines these compounds by ion chromatography. It also has capabilities of determining PO_4^{2-} using a different method and extraction (Lachat Instruments, 2002).

CHAPTER IV

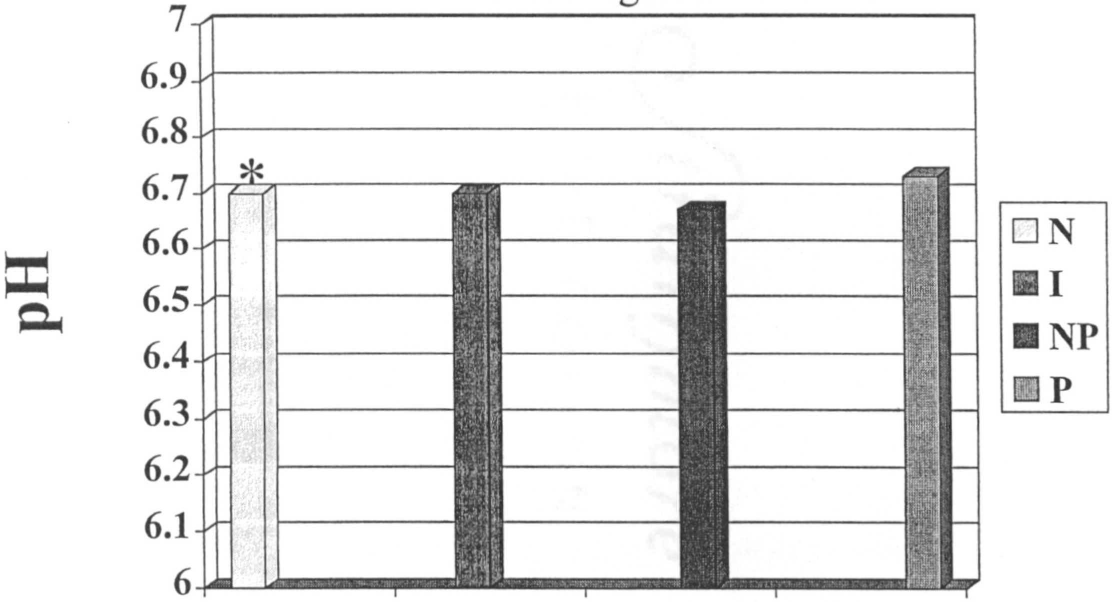
RESULTS AND DISCUSSION

Soil Samples in Orchardgrass

Soil samples were representative of four harvests throughout the growing season. Water pH did not exhibit differences, indicating that it is not believed to be altering nutrient availability (Fig. 1). Jones et al. (1973) found higher soil pH in littered vs. nonlittered tall fescue pastures in Georgia. Furthermore, Hue (1992) showed that chicken manure was as effective as $Ca(OH)_2$ in raising soil pH. However, Kingery et al. (1993) and Kingery et al. (1994) found that by-depth comparison of soil pH distribution from littered and nonlittered pastures indicated that long-term litter application caused an increase of approximately 0.5 units in a 0- to 60-cm depth interval. These results are in contrast to those of Jackson et al. (1977) who found that poultry litter was not altering pH when applied to a Cecil soil.

Nitrate amounts were greater in treatments N and NP compared to P and the I was equal to all of the treatments (Fig. 2). No other differences in ammonium concentrations were observed (Fig. 3). One possible explanation could be large amounts of litter used in treatment N and supplemental N fertilizer along with litter used in the NP treatment. Kingery et al. (1993) found that long-term litter applications, as compared to no-litter, resulted in an accumulation of soil organic matter and total N. An accumulation of total N due to litter application is consistent with findings of Huneycutt et al., (1988.) In this study, 2206 kg litter ha^{-1} was added which contained approximately 218 kg of total

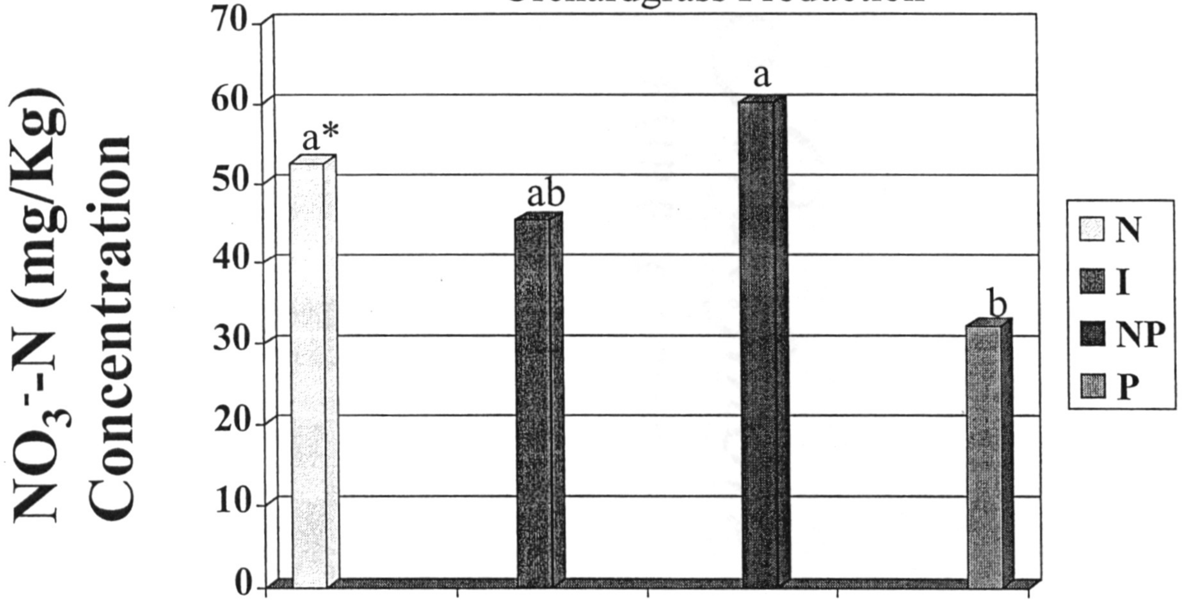
Figure 1. Comparison of Water pH in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Orchardgrass Production



* Means sharing the same letter are not different (p<=0.05).

Treatments

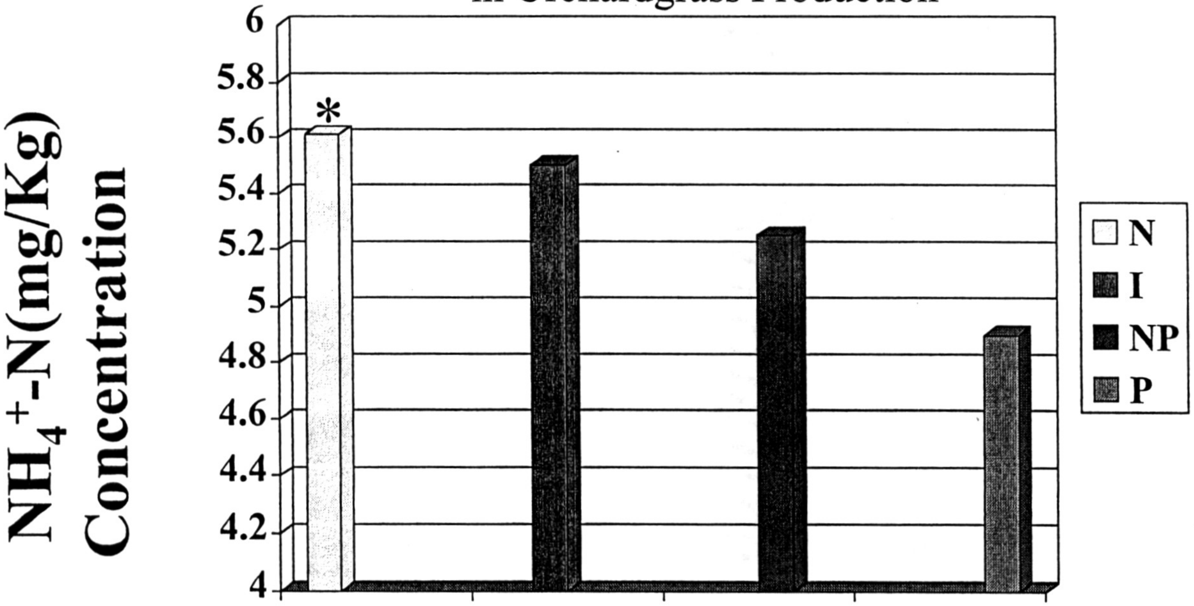
Figure 2. Comparison of Nitrate Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Orchardgrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

Figure 3. Comparison of Ammonium Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Orchardgrass Production



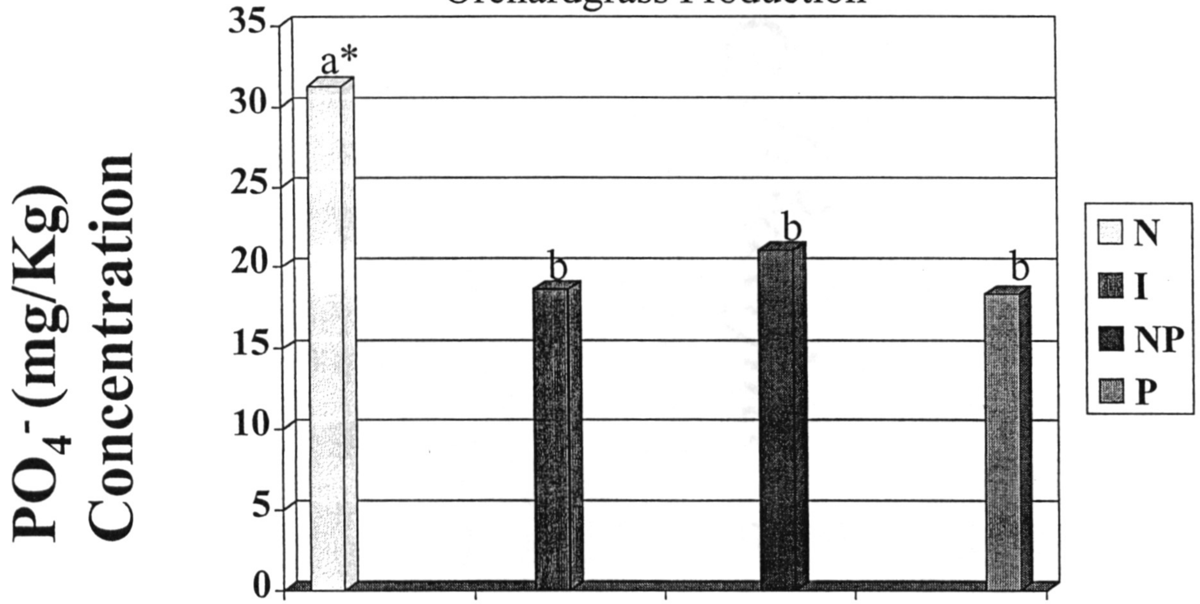
* Means sharing the same letter are not different (p<=0.01).

Treatments

N when applied to tall fescue it produced yields equivalent to commercial fertilizer rates of 37 to 55 kg N ha^{-1}. By assuming that approximately 60% of N in litter became available through mineralization/release, it was estimated that about 42 kg ha^{-1} of applied N was supplied to tall fescue annually. These results suggest that there was a significant pool of residual N associated with each application.

Phosphate levels were higher in treatment N than all other treatments (Fig. 4). These values were anticipated due to high amounts of poultry litter used in treatment N. Kingery et al. (1994) found that profile distributions of extractable P indicate both accumulation and some downward movement in littered soils compared with nonlittered soils down to a depth of approximately 60 cm. Long-term land application of broiler litter increased soil P concentrations more than six times that of nonlittered soils in the 0- to 60-cm depth interval. Phosphorous concentrations measured in the 0- to 15-cm depth in litter sites have a rating of "extremely high" according to the Auburn University Soil Testing Laboratory. Phosphorous concentrations of 20 mg kg^{-1} are considered to be adequate for tall fescue production on these soils (Cope et al., 1981). These data suggest that litter applications, which are typically based on litter N content, can result in excessive accumulation of soil P. Because of large amounts of accumulated soil P associated with litter applications, P-loading criteria should be a fundamental component of litter application guidelines (Kingery et al., 1993). High P concentrations have been documented in runoff water from pastures fertilized with low to moderate amounts of poultry manure, causing concerns over the utilization of this valuable resource in areas of the U.S. where poultry production is high (Edwards and Daniel, 1992a and 1992b; Sims and Wolf, 1994). Phosphorous is normally a limiting element for eutrophication in

Figure 4. Comparison of Phosphate Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Orchardgrass Production



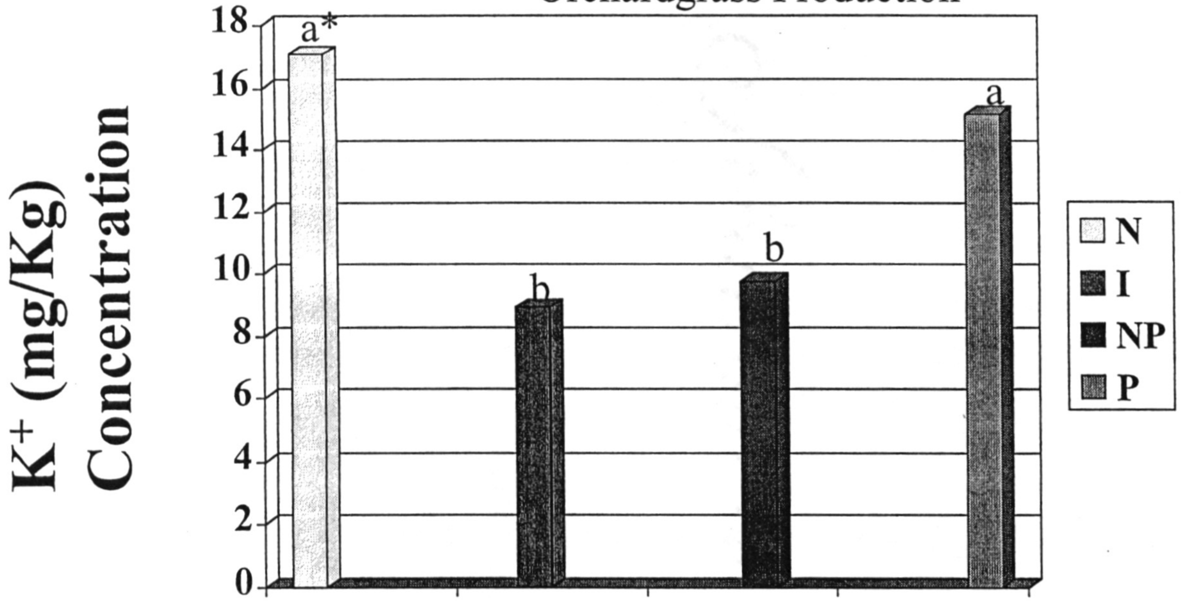
* Means sharing the same letter are not different (p<=0.01).

Treatments

freshwater bodies, such as rivers, lakes, and reservoirs (Schindler, 1977). The majority (80-90%) of the P in runoff water from fields fertilized with poultry litter is dissolved P, which is in the form most readily available to algae (Edwards and Daniel, 1993; Sonzogni et al., 1982).

Potassium concentrations were higher in the N and P treatments than those of NP and I (Fig. 5). At this time, it is uncertain why this difference occurred in the P treatment since very little litter was added. Kingery et al. (1994) found that long-term litter application has resulted in greater soil concentrations of extractable K, Ca, and Mg compared with no litter. Elevated levels of these elements in littered soils reflect results of a survey of broiler litter collected from 20 counties in Alabama in which Stephenson et al. (1990) found an average of 23, 23, and 5g kg^{-1} dry matter for K, Ca, and Mg, respectively. Soil K concentrations were significantly greater in littered soils compared with nonlittered soils for the first two depths (0- to 60-cm). Impact of broiler litter on soil concentrations of Ca was greatest at shallower depths (littered soils were found to have about 800 mg kg^{-1} more Ca in upper 15 cm than nonlittered soils). Relative to nonlittered soils, Ca from litter has migrated to a depth of approximately 140 cm. Throughout profile depths, Mg levels were higher in littered applied plots. Differences between littered and nonlittered were most pronounced near the surface (50 mg kg^{-1} for 0 to 15 cm) and at lower depths where the average amount of Ca was 16.5 mg kg^{-1} (230- to 290-cm depth interval). Potassium, Ca, and Mg concentrations under litter-amended pastures are more than adequate for tall fescue production on these soil series (Cope et al., 1981). Apparent downward mobility of these elements is consistent with findings of Jackson et al. (1975), who examined movement in soils of water soluble forms following semi-

Figure 5. Comparison of Potassium Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Orchardgrass Production



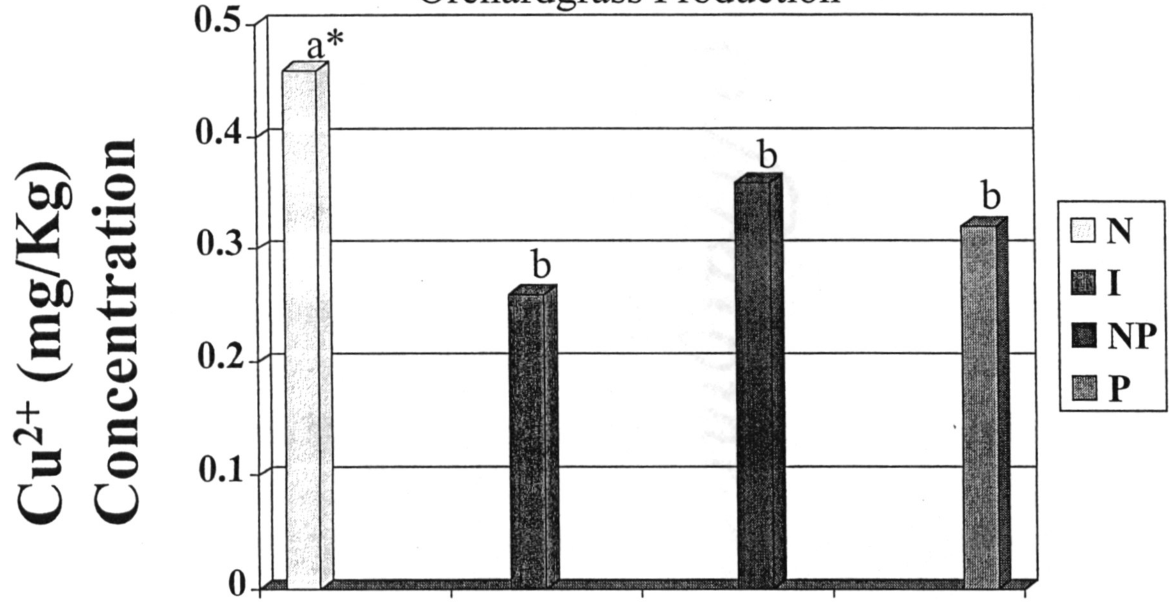
* Means sharing the same letter are not different (p<=0.01).

Treatments

annual poultry manure application for two years. Our results were not entirely consistent with these findings for K, Ca, and Mg, which exhibited no statistical differences among soil samples during the first season ($p<=0.05$, data not shown).

The N treatment increased Cu and Zn concentration when compared to those of the remaining three treatments (Figs. 6 & 7). These results were not unexpected since Cu and Zn concentrations in litter average approximately 0.4 and 0.3 g kg^{-1} of litter, respectively (Kingery et al., 1993). Poultry litter often contains fairly high concentrations of heavy metals (Sims and Wolf, 1994; Moore et al., 1995). Tufft and Nockels (1991) indicated that As, Co, Cu, Fe, Mn, Se, and Zn are added to poultry diets to prevent diseases, improve weight gains and feed conversion, and increase egg production. Most metals that are added pass directly through the bird, which leads to elevated levels in manure. Several workers have shown that soils receiving applications of poultry litter for many years have high concentrations of As, Cu, and Zn, particularly near the soil surface (van der Watt et al., 1994; Kingery et al., 1994). These studies indicate a potential for non-point source metal pollution from fields fertilized with poultry litter. Our findings suggest an accumulation of Cu and Zn after one growing season, already indicating potential for non-point source pollution from runoff, even in sorghum-sudangrass which has high capacity for removing nutrients from sites receiving application (Redmon, 1996).

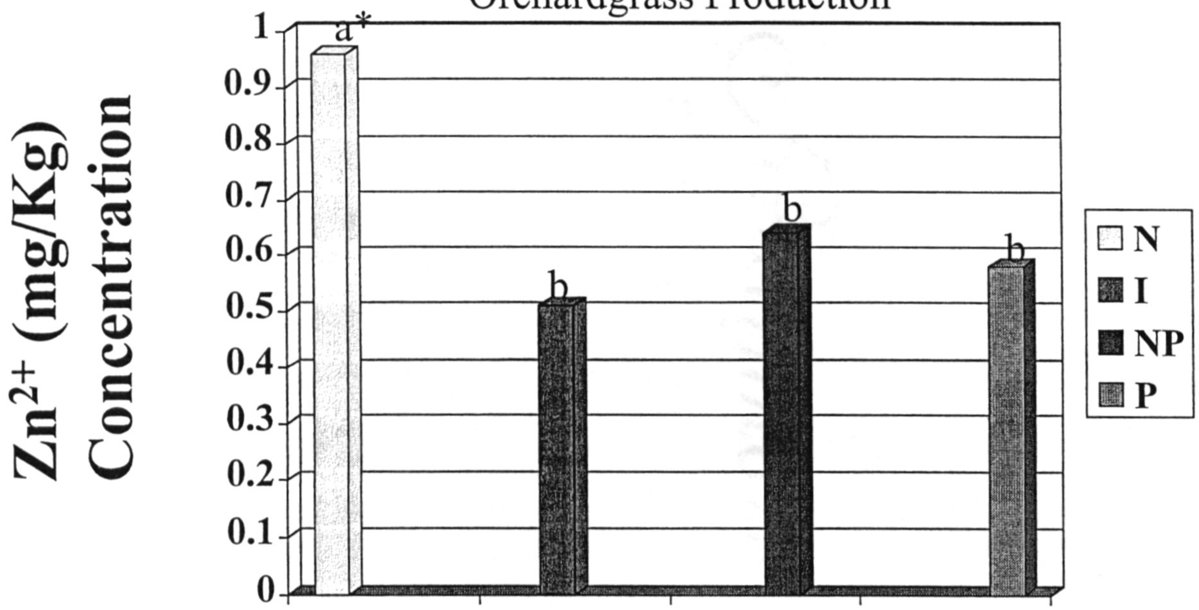
Figure 6. Comparison of Copper Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Orchardgrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

Figure 7. Comparison of Zinc Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Orchardgrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

Soil Samples in Sorgum-Sudangrass

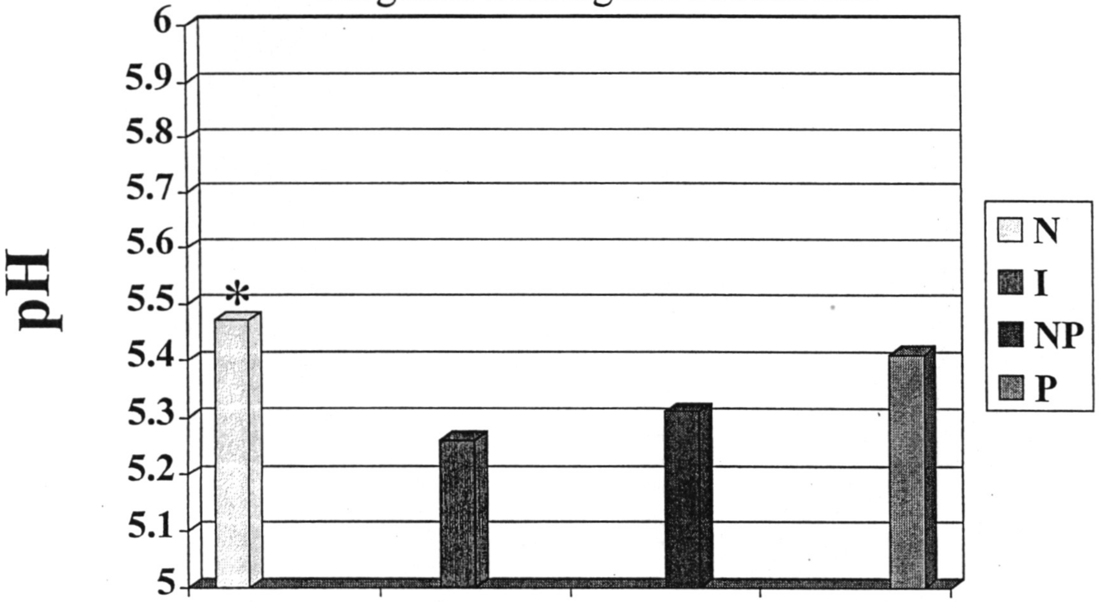
Sorghum-sudangrass results include the first two harvests of the growing season. Water pH is reflective of the orchardgrass soil, indicating no differences among treatments at this time (Fig. 8).

Nitrate results for sorghum-sudangrass soils indicated that the I treatment was significantly higher than all other treatments ($p<=0.01$). The N and NP treatments were similar in nitrate concentration, while the P was lower than the N treatment. These results are most likely due to the large quantities of inorganic fertilizer applied in a tilled system (Fig. 9). Nutrients applied to a tilled system move within the soil profile more quickly and easily than those applied to a non-tilled system such as pasture or hayfields due to larger pore space. Ammonium results for sorghum-sudangrass soils indicated the N, I, and NP were all similar but the I was greater than the P treatment ($p<=0.05$) (Fig. 10). This difference is likely attributed to the readily available N in treatment I and the small amount of poultry litter used in treatment P.

Findings for PO_4 are consistent with those of the orchardgrass soil. Treatment N had PO_4 concentrations higher than I, NP, and P treatments ($p<=0.01$) (Fig. 11). As with the orchardgrass soils, large amounts of litter applied has contributed to the difference in treatment N from all other treatments.

Sorghum-sudangrass soils results for Mg indicated that treatment N was significantly higher from the remaining three treatments (Fig. 12) which is similar of the findings of Cope et al. (1981) who found that concentrations of Mg were more than adequate under litter amended soils. Potassium exhibited the same results as Mg, with

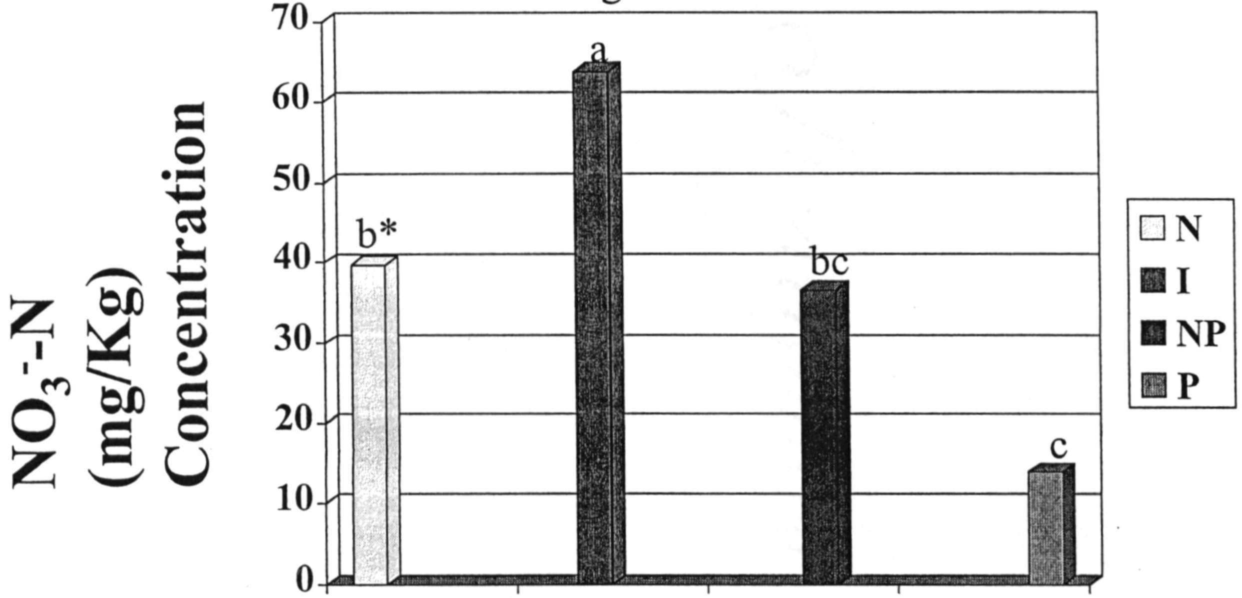
Figure 8. Comparison of Water pH in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Sorghum-Sudangrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

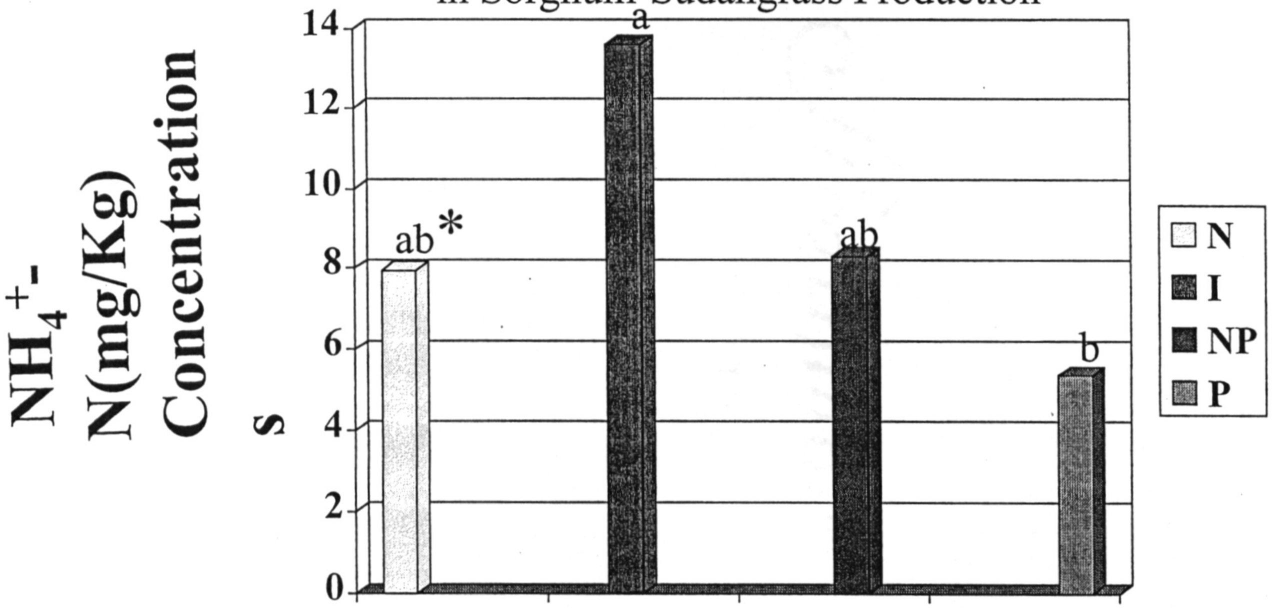
Figure 9. Comparison of Nitrate Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Sorghum-Sudangrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

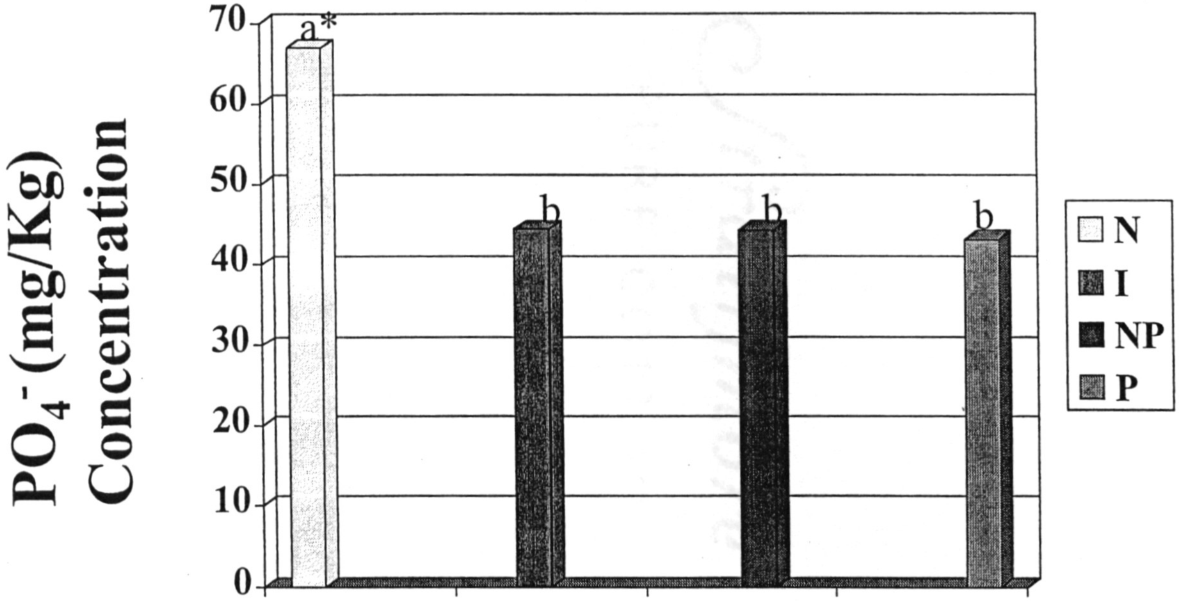
Figure 10. Comparison of Ammonium Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Sorghum-Sudangrass Production



* Means sharing the same letter are not different (p<=0.05).

Treatments

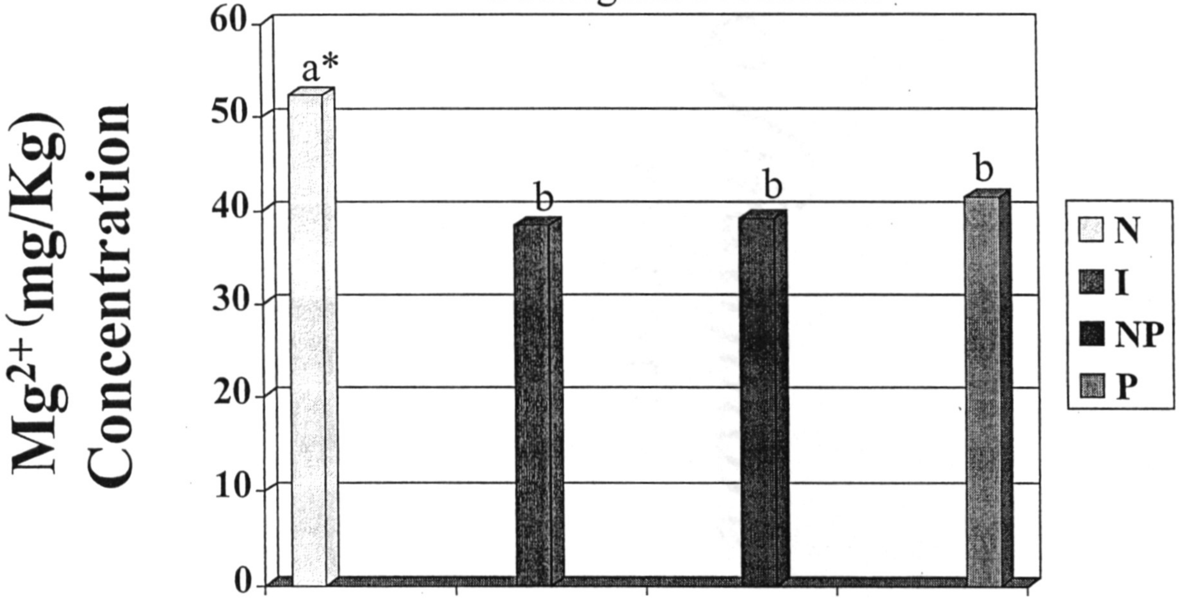
Figure 11. Comparison of Phosphate Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Sorghum-Sudangrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

Figure 12. Comparison of Magnesium Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Sorghum-Sudangrass Production



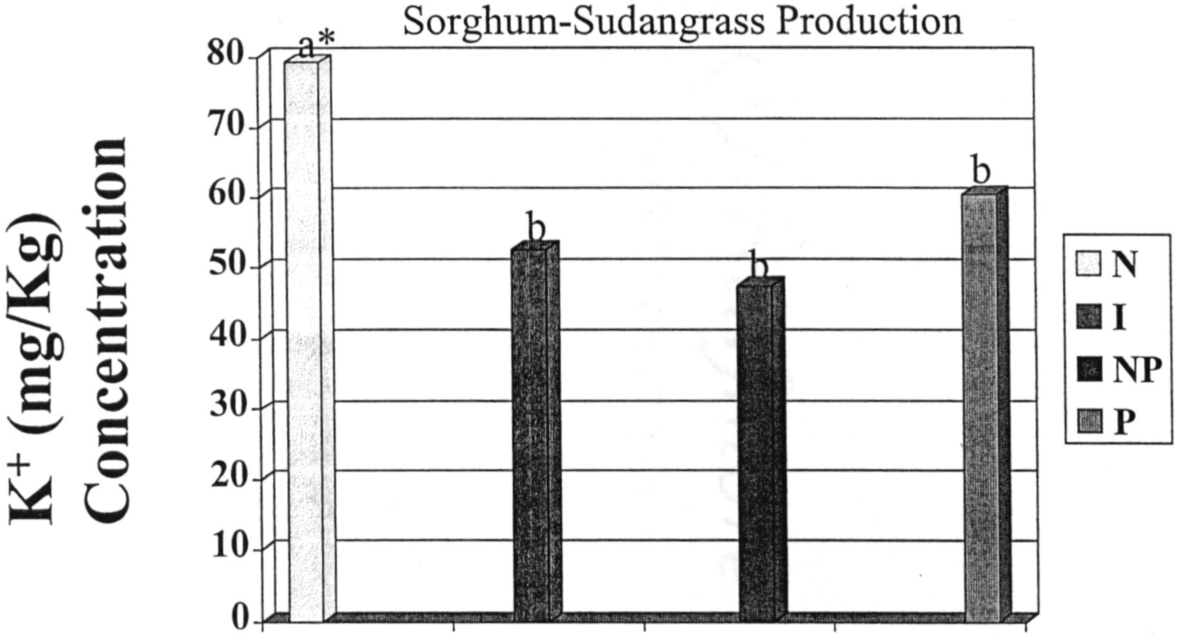
* Means sharing the same letter are not different (p<=0.01).

Treatments

treatment N exhibiting a greater difference than treatments I, NP, and P (Fig.13). These findings are likely attributed to the large quantity of litter used in treatment N.

Cu and Zn concentrations were consistent with the results of the orchardgrass soils. The N treatment exhibited higher Cu and Zn concentrations than the remaining three treatments ($p=<0.01$) (Figs. 14,15), this is directly related to the metals added to feed rations and thus present in manure/litter. Poultry litter already contains an abundance of metals in the ration that is expelled from the bird in a manure form. Because larger quantities of litter were used in treatment N than all other treatments, it was anticipated that a significant difference in this treatment would be present in comparison to the remaining three treatments.

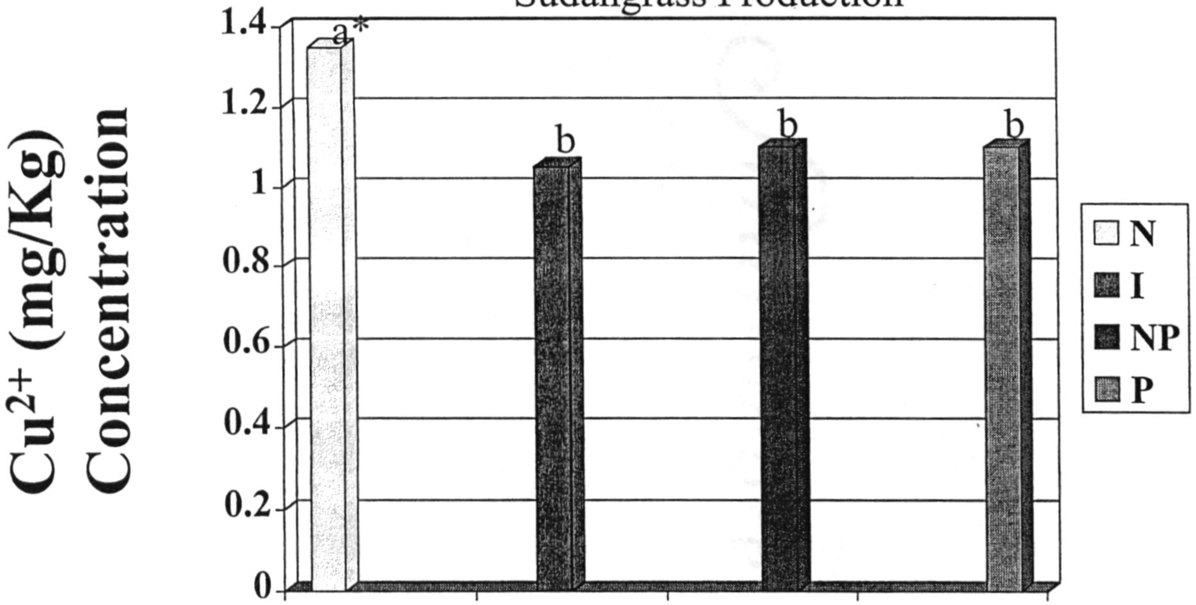
Figure 13. Comparison of Potassium Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Sorghum-Sudangrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

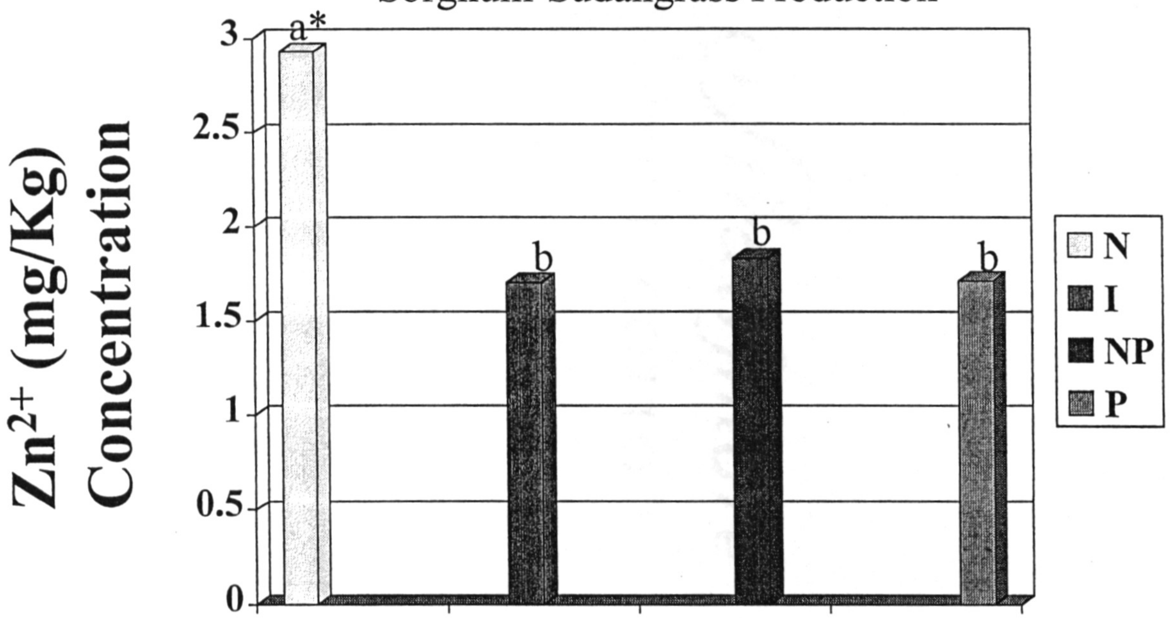
Figure 14. Comparison of Copper Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Sorghum-Sudangrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

Figure 15. Comparison of Zinc Concentration in Soils Fertilized with Poultry Litter or Inorganic Fertilizer in Sorghum-Sudangrass Production



* Means sharing the same letter are not different (p<=0.01).

Treatments

CHAPTER V

CONCLUSIONS

From the soil samples taken during 2001 we observed that water pH has remained equal in all treatments. Nitrate concentration increased in treatments N and P for orchardgrass hayfield soils, while sorgum-sudangrass hayfield soils indicated all three treatments N, I, and P were different from each other. There were no differences among treatments for ammonium in orchardgrass hayfield soils; however, sorghum-sudangrass hayfield soils exhibited a higher concentration in treatments P and I. Phosphorous concentrations in orchardgrass and sorghum-sudangrass hayfield soils were higher in treatment N over all other treatments. Potassium concentrations were higher in treatments P and N in sorghum-sudangrass hayfield soils and the NP and I treatments in orchardgrass hayfield soils. Sorghum-sudangrass hayfield soils indicated a higher K concentration in treatment N from all other treatments. While orchardgrass hayfield soils exhibited no difference in Mg, sorghum-sudangrass hayfield soils indicated a higher amount in treatment N from all other treatments. Copper and Zn both exhibited a higher concentration in treatment N in comparison to all other treatments in both orchardgrass and sorghum-sudangrass hayfield soils.

CHAPTER VI

LITERATURE CITED

1. Alabama Extension Service. 1992. Questions and Answers About Fertilizing with Poultry Litter. Alabama A&M and Auburn University.

2. Arkansas Department of Pollution Control and Ecology. 1990. *Arkansas Water Quality Inventory Report.* Little Rock, Ark.

3. Ball, D.M., C.S. Hoveland, and G.D. Lacefield. 1991. Southern Forages. Potash and Phosphate Institute, Norcross, GA.

4. Buchberger, E. 1991. An economic and environmental analysis of land application of poultry litter in Northwest Arkansas. Department of Agricultural Economics and Rural Sociology, University of Arkansas, Fayetteville.

5. Buchberger, E., M.J. Cochran, and R. Govindasamy. 1993. Optimal poultry litter management strategies for better environmental quality. Staff Paper, SP0193. Department of Agricultural Economics and Rural Sociology, University of Arkansas, Fayetteville.

6. Carter, M.R. Soil Sampling and Methods of Analysis. 1993. Lewis Publishers.

7. Cope, J.T., C.E. Evans, and H.C. Williams. 1981. Soil-test fertilizer recommendations for Alabama crops. Alabama Agric. Exp. St. Circ. 251.

8. Edwards, D.R., and T.C. Daniel. 1993. Abstraction and runoff from fescue plots receiving poultry litter and swine manure. American Society of Agricultural Engineers, vol. 36 (2).

9. Edwards, D.R. and T.C. Daniel. 1992a. Environmental impacts of on-farm poultry waste disposal—A review. Bioresour. Technol. 41:9-33.

10. Edwards, D.R., and T.C. Daniel. 1992b. Potential runoff quality effects of poultry litter slurry applied to fescue plots. Am. Soc. Agric. Eng. 35:1827-1832.

11. Edwards, D.R., P.A. Moore, Jr., T.C. Daniel, P. Srivastava, and D.J. Nichols. 1997. Vegetative filter strip removal of metals in runoff from poultry litter-amended fescuegrass plots. Trans. ASAE 40:121-127.

12. Govindasamy, R., M.J. Cochran, and E. Buchberger. 1994. Economic implications of phosphorous loading policies for pasture land applications of poultry litter. Water Resources Bulletin, vol. 30, no. 5.

13. Havlin, J.L., J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 1999. Soil Fertility and Fertilizers. Pgs. 168-174. Sixth Edition. Prentice Hall, Inc.

14. Hue, N.V. 1992. Correcting soil acidity of a highly weathered ultisol with chicken manure and sewage sludge. Commun. Soil Sci. Plant Anal. 23:241-264.

15. Huneycutt, H.G., C.P. West, and J.M. Phillips. 1988. Responses of bermudagrass, tall fescue, and tall fescue-clover to broiler litter and commercial fertilizer. Bull. 913. Arkansas Agricultural Experiment Station, University of Arkansas, Fayetteville.

16. Jackson, W.A., R.A. Leonard, and S.R. Wilkinson. 1975. Land disposal of broiler litter: Changes in potassium, calcium, and magnesium. J. Environ. Qual. 4 :202-206.

17. Jackson, W.A., W.A. Wilkinson, and R.A. Leonard. 1977. Land disposal of broiler litter: Changes in concentration of chloride, nitrate nitrogen, total nitrogen, and organic matter in a Cecil sandy loam. J. Environ. Qual. 6 :58-62.

18. Jones, J.B., Jr., J.A. Stuedemann, S.R. Wilkinson, and J.W. Dobson, Jr. 1973. Grass tetany alert program in north Georgia—1972. Ga. Agric. Res. 14:9-12.

19. Jongbloed, A.W., and N.P. Lenis. 1998. Environmental concerns about animal manure. J. Anim. Sci. 76:2648-2651.

20. Kentucky Agricultural Statistics. 2000-2001. Kentucky Department of Agriculture. Frankfort, KY.

21. Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. Williams, and G.L. Mullins. 1994. Impact of long-term land application of broiler litter on environmentally related soil properties. J. Environ. Qual. 23:139-147.

22. Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. Williams, G.L. Mullins, and E. van Santen. 1993. Implications of long-term land application of poultry litter on tall fescue patures. J. Prod. Agric., 6:3.

23. Kunkle, W.E., L.E. Carr, T.A. Carter, and E.H. Bossard. 1981. Effect of flock and floor type on the levels of nutrient and heavy metals in broiler litter. Poultry Sci. 60:1160-1164.

24. Lachat Instruments. 2002. Milwaukee, WI.

25. Madison, R.J., and J.O. Brunett. 1985. Over view of the occurrence of nitrate in groundwater in the United States. U.S. Geological Survey, Water Supply Paper 2275, pp.93-106.

26. Miller, R.W., and R.L. Donahue. 1995. Soils in Our Environment. Pgs. 320-326. Seventh Edition. Prenctice Hall Career and Technology.

27. Moore, P.A., Jr., T.C. Daniel, C.W. Wood, and A.N. Sharpley. 1995. Poultry manure management. J. Soil Water Conserv. 50:29-35.

28. Morrison, J.L. 1969. Distribution of arsenic from poultry litter in broiler chickens, soils, and crops. J. Agric. Food Chem. 17:1288-1290.

29. National Agricultural Statistics Service. 2002. www.nass.usda.gov/ky.

30. The Ohio State University. 1990. Poultry Manure Management and Utilization Problems and Opportunities.

31. Page, A.L., R.H. Miller, and D.R. Keeney. 1982. Methods of Soil Analysis. Part 2-Chemical and Microbiological Properties. Second Edition. American Society of Agronomy, Inc. and Soil Science Society of America, Inc. Madison, WI.

32. Pederson, G.A. 2002. Using hay fields to improve manure management. Waste Management and Forage Research Unit, Mississippi State, Mississippi.

33. Poultry Water Quality Handbook. 1998. Second Edition Expanded. Chattanooga, TN.

34. Redmon, L.A. 1996. Selecting forages for nutrient recycling. Division of Agricultural Sciences and Natural Resources, Oklahoma State University.

35. Sampling Poultry Litter for Nutrient Testing. 1999. University of Missouri.

36. Schindler, D.W. 1977. The evolution of phosphorous limitation in lakes. Science (Washington, D.C.) 195: 260-262.

37. Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel, and K.R. Reddy. 1994. Managing agricultural phosphorous for protection of surface waters: Issues and options. J. Environ. Qual. 23 :437-451.

38. Sims, J.T., and D.C. Wolf. 1994. Poultry manure management: Agricultural and environmental issues. Adv. Agron. 52:1-83.

39. Skillman, L. January 26, 2000. Poultry's Promise. Messenger-Inquirer.

40. Sonzogni, W.C., S.C. Chapra, D.E. Armstrong, and T.J. Logan. 1982. Bioavailability of phosphorous inputs to lakes. J. Environ. Qual. 11 :555-563.

41. Steele, K.F., W.K. McCallister, and J.C. Adamski. 1990. Nitrate and bacterial contamination of limestone aquifers in poultry cattle production areas of Northwestern Arkansas, U.S.A. Fourth International Conference on Environmental Contamination, October, Barcelona.

42. Stephenson, A.H., T.A. McCaskey, and B.G. Ruffin. 1990. A survey of broiler litter composition and potential value as a nutrient source. Biol. Wastes 34:1-9.

43. Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1985. Soil Fertility and Fertilizers. Fourth Edition. Macmillan Publishing Company, New York, New York.

44. Tufft, L.S. and C.F. Nockels. 1991. The effects of stress, *Escherichia coli*, dietary ETA, and their interaction of tissue trace elements in chicks. Poult. Sci. 70:2439-2449.

45. University of Missouri Extension Service. 1999. Sampling Poultry Litter for Nutrient Testing. Publication G9340.

46. U.S. Department of Agriculture. 1992. www.usda.gov

47. U.S. Environmental Protection Agency. 1976. Quality criteria for water. U.S. Gov. Print. Office, Washington, D.C.

48. van der Watt, H.v.H., M.E. Summer, and M.L. Cabrera. 1994. Bioavailability of copper, manganese, and zinc in poultry litter. J. Environ. Qual. 23:43-49.